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EXPERIENCES OF CNES AND SEP ON SPACE MECHANISMS ROTATING AT LOW SPEED

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I INTRODUCTION

This paper describes some aspects of knowledge acquired in the field of space mechanisms by SEP and CNES in International and French National space programmes. The experience described centres on the development of the following major mechanism programmes :

- The MEGS (Mechanisme d'Entraînement du Générateur Solaire)

This is a solar array drive mechanism developed and flown under a CNES led programme and is now flying on the Earth Observation SPOT 1 satellite.

- The MOGS (Mecanisme d'Orientation de Générateur Solaire)

This is a Solar Array Drive designed by SEP under CNES contract and currently being developed for application in the EUTELSAT II programme.

For these mechanisms, the paper highlights key design areas and the mechanism performance obtained. Some test problems with the MEGS sliprings are discussed.

II THE MEGS (Mecanisme d'Entraînement du Générateur Solaire)

II-1 The Major Requirement

The SPOT Mission was to provide precise images of the Earth, these images having a resolution of 10 meters. This was a very severe requirement for the control stability of the satellite, and made large corresponding demands on the stability and uniformity of motion made by the MEGS. This speed stability was required to remain within 10% of the nominal speed of 1 rev/100 minutes (no stepping was allowed). Particularly important was the avoidance of frequencies between 0.15 and 0.2 Hz which might have excited the Solar Arrays. The MEGS is shown in Figure 1.

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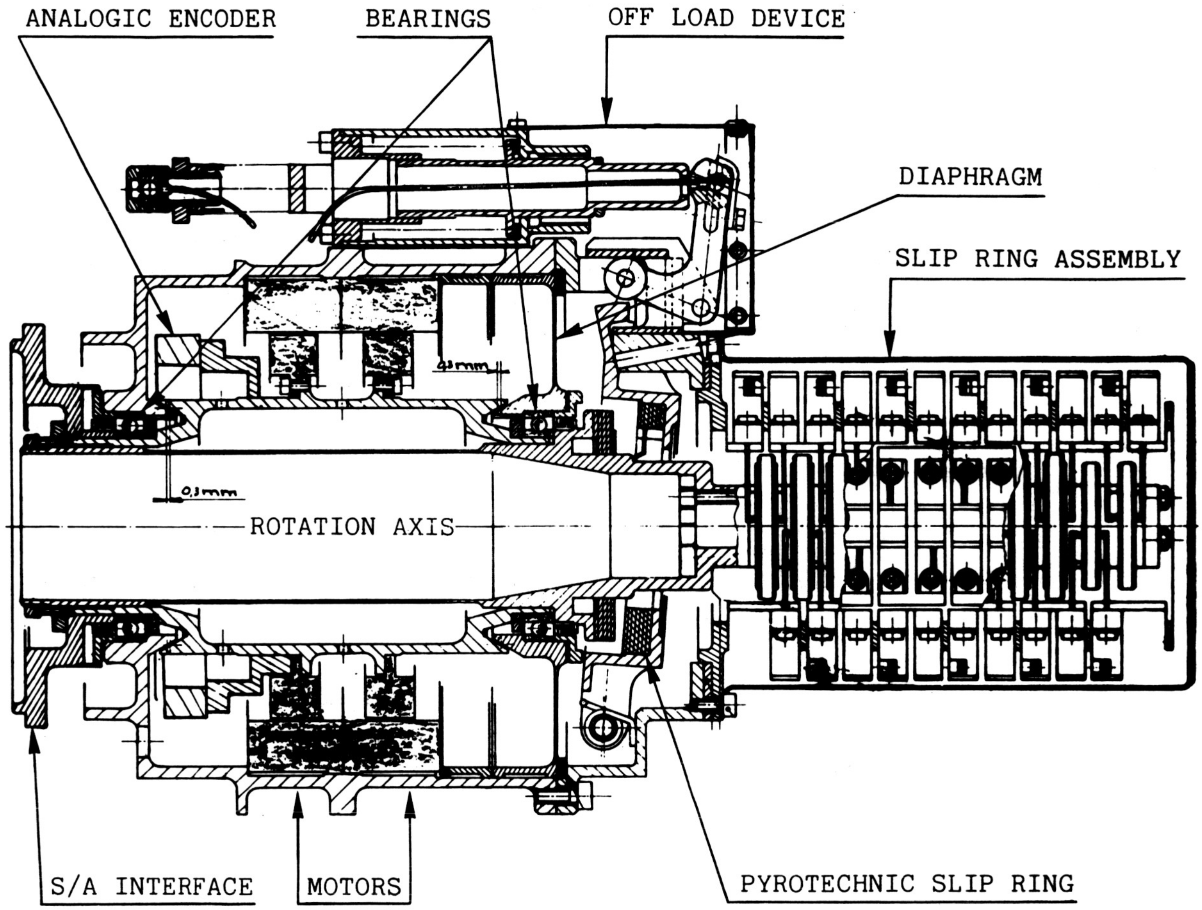


M E G S

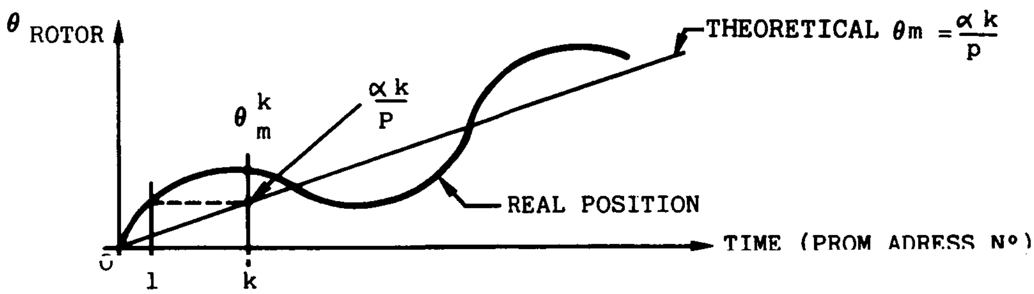
(Mécanisme d'Entraînement du Générateur Solaire)

Figure 1

II-2 The Drive System

In order to achieve these speed uniformity requirements, a direct drive design was chosen. The motor selected was a SAGEM variable reluctance stepper motor (nominal 1200 steps per revolution), but not driven in "stepping mode", but in "synchronous mode". This is achieved by applying, to adjacent motor coils, currents which vary sinusoidally in time, the current in adjacent coils being out of phase by π . This has the effect of moving the "detent position" of the motor progressively in the desired direction at, for a "perfect motor", a constant speed. However since the coils of the motor are not absolutely identical either electrically or physically, some small variation can occur. There can also be interaction with resistive torques arising from position or time dependant friction.

A similar synchronous drive technique was applied by SEP to the Despin Mechanism of the ESA Satellite GIOTTO. This Despin Mechanism is still operating successfully after the encounter with the Halley comet.



Schematic of variation in synchronous drive

Figure 2

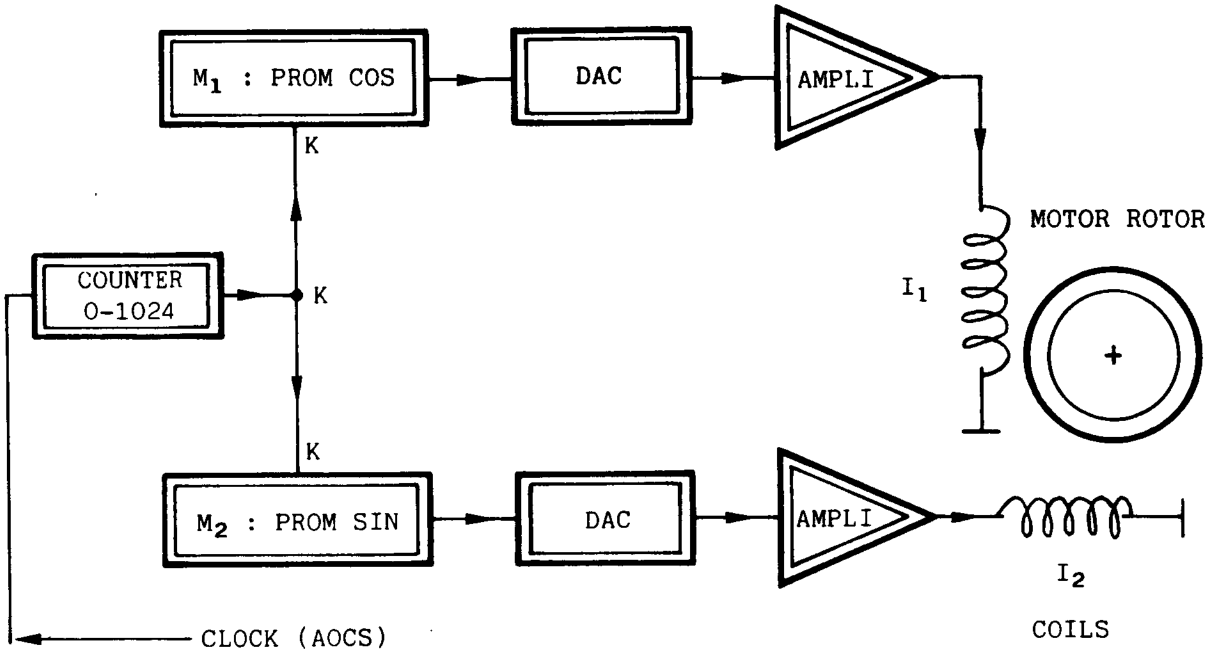
As shown schematically in Figure 2, the sinusoidal current demand produces a constant speed with a certain speed modulation or error. The displacement is given by :

$$\theta_m = \frac{\alpha k}{p} + \mathcal{E}(\alpha k) + \delta = G(\alpha k)$$

where p = number of sinusoidal cycles per motor revolution
(p = 300 for the SAGEM motor chosen).
δ is an irreducible random error and $\mathcal{E}(\alpha k)$ is due to miscellaneous defects in the control loop and the motor.

note that if the drive were perfect $\omega t = p\,\theta_m$
were θm is the angular motor position.

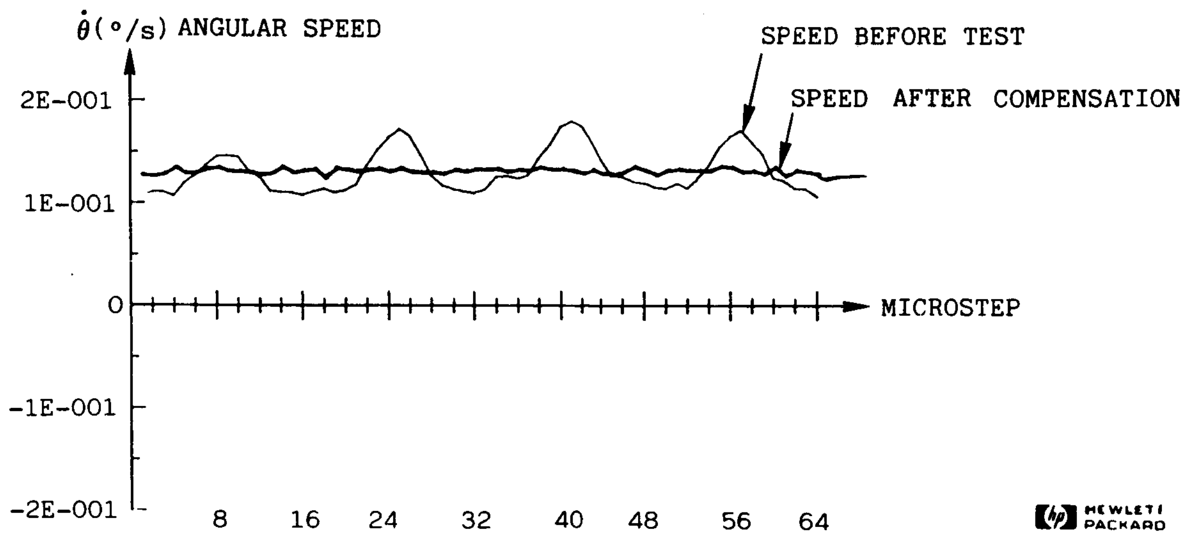
Figure 3 shows the circuit which was selected to provide the sinusoidal command ; PROMS provide the sinusoidal reference.



Circuit used to obtain a sinusoidal command current

Figure 3

The actual speed variation can be measured by means of a gyrometer mounted on the motor shaft. This has been performed during ground testing (ie without an attached inertia) and the results are shown in Figure 4.



MEGS SPEED ACCURACY MEASURED DURING GROUND TESTING

Figure 4

The larger of the two errors shown indicates the result when a pure sinusoidal current is utilised for the synchronous drive. Analysis of this result enables a modified, or compensated, "sinusoidal" drive profile to be derived which departs from the pure sinusoid and reduces the systematic errors. Thus the drive circuit PROMS contain the two functions.

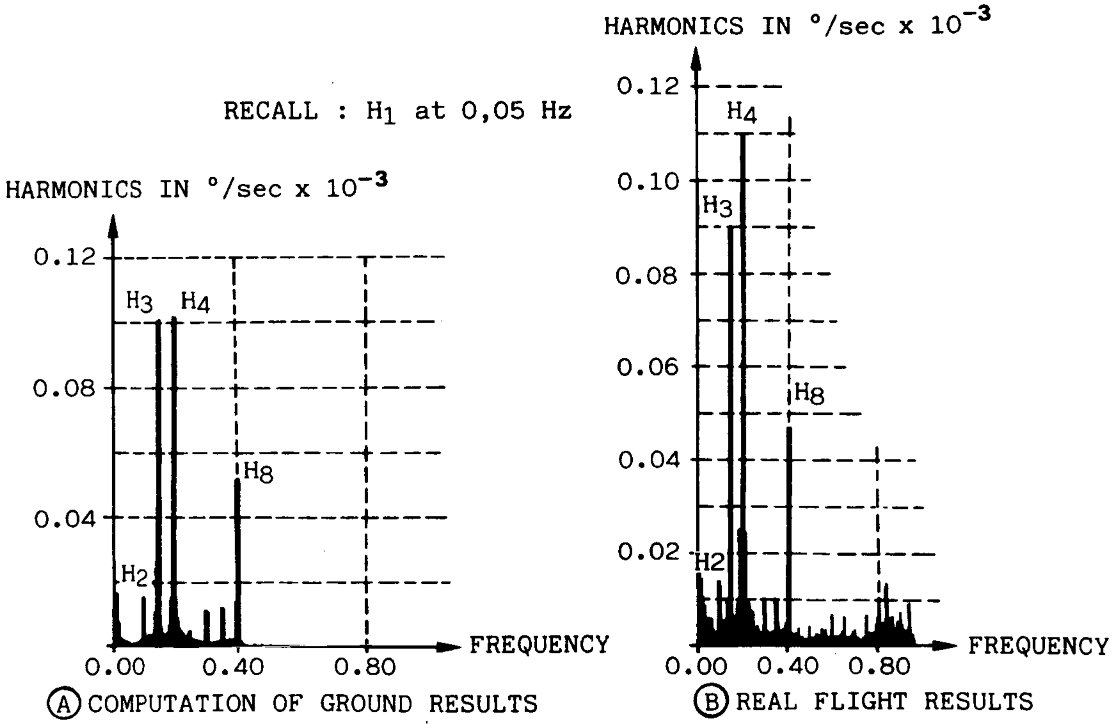
$$I_1 = I_0 \cos \alpha'_k. \quad \text{and} \quad I_2 = I_0 \sin \alpha'_k$$

where $\alpha'k$ is the compensated form of αk. ; $\alpha'k = \alpha 1$ see figure 2.

Flight measurements have been made on the SPOT 1 satellite, and the results are shown in Figure 5 and Table 1, which also shows the results of ground testing in air. H1 to H8 represent the harmonics of the speed variation, expressed in percent, which were derived for the flight case at different orbit positions.

IN FLIGHT				ON GROUND + 20°C		
IN ORBIT POSITION	107 110°	140 200°	140 95°	MEASURE 1	MEASURE 2	MEASURE 3
H1 (%)	Noise			1.75	2.24	1.53
H2 (%)	0.73	0.65	0.64	0.53	0.83	0.36
H3 (%)	0.51	0.59	0.56	0.56	0.63	0.41
H4 (%)	2.43	2.02	2.41	0.63	0.73	1.26
H5 (%)	0	0.18	0.34	-	-	-
H6 (%)	0.53	0.37	0.56	-	-	-
H7 (%)	0.69	0.62	0.64	-	-	-
H8 (%)	3.33	2.69	3.23	2.67	2.96	2.77

TABLE 1 Comparison of flight and ground performance data

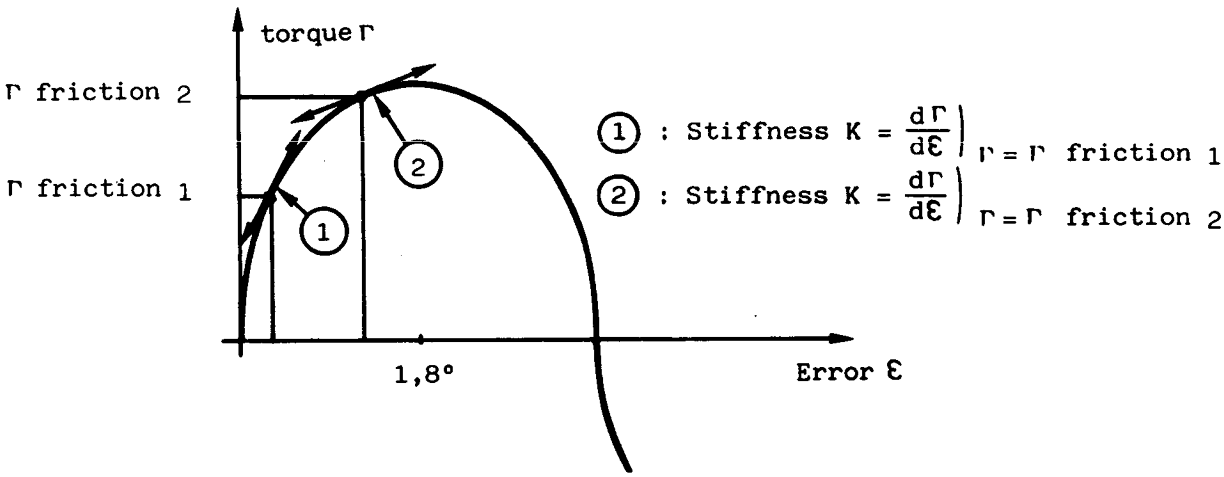


MEGS orbital performance measurements

Figure 5

It can be seen that H1 is not measurable in the flight case and is in any event less than on ground. The reason for this change is not yet clear but could derive from a change in the compensation parameters.

H2, H3 and H8 are remarkably similar to the ground test results. H4, on the other hand, is significantly greater. It is thought that this change comes from the altered slipring friction torques in vacuum, which have the effect of modifying the equilibrium or detent position which the motor assumes during its movement. The effective torque of the motor around the detent position is shown in Figure 6.



Schematic of Detent position motor torques

Figure 6

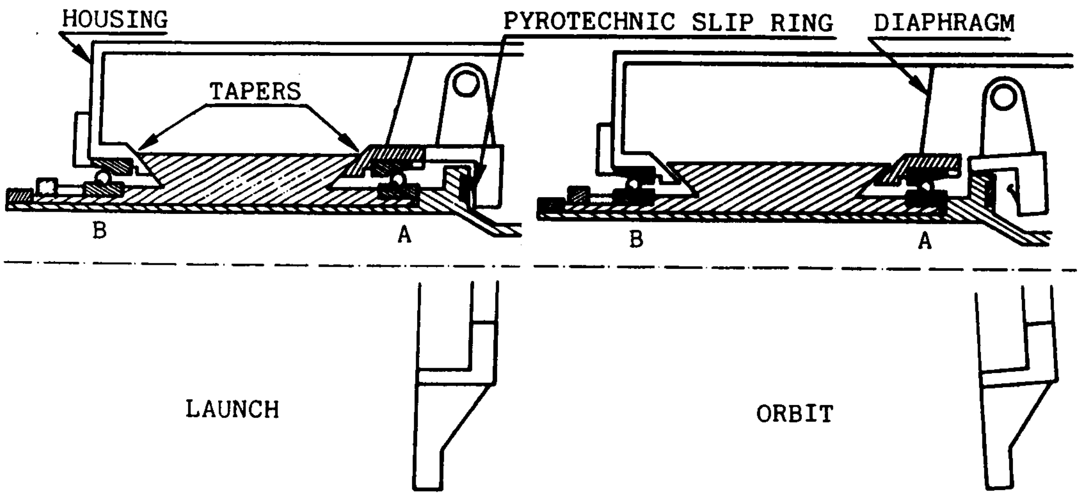
The motor torque acts against the rotor and is resisted by the frictional torques in the MEGS. If those torques change, due for example to an increase in friction of the bearings or the slipring unit, then the equilibrium point also changes, with consequent effect on the speed stability.

The change in H4 from an average, during ground testing, of 0.9% to an average of around 2.2% in flight can be correlated with the frictional change in the sliprings. In fact there is an almost linear relationship between the resistive friction and the 4th harmonic such that a 0.1Nm change in friction equates with a 1% change in H4. The observed change in H4 is therefore thought to correspond with an expected change in friction of the MoS2/Ag/C brushes against the silver slipring where the nominal friction torque was 0.2Nm to 0.3Nm in vacuum compared with 0.4Nm to 0.6Nm in air.

II-3 Bearing Off-Load Device

Special attention was given to the protection of the bearings during launch, and maintaining the uniformity of their resistance torque in operation.

The bearings selected were 25 deg angular contact bearings SNFA SEA 55, lead lubricated according to an ESTL procedure (lead coated races with a lead bronze cage). This combination of bearing and lubrication is suited to low speeds with low wear, and gives a satisfactory low torque and low torque noise. Moreover, due to the dry lubrication, an accelerated life test can be done.



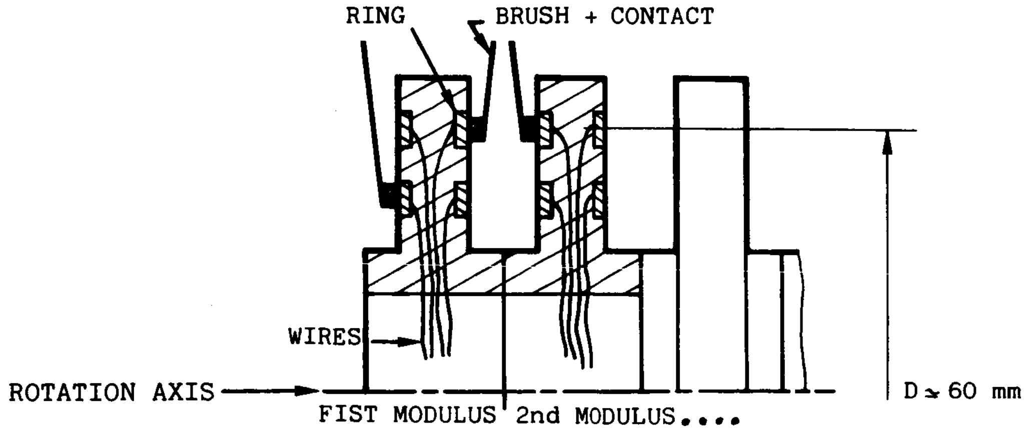
MEGS Bearing Mounting and Off-load Device

Figure 7

Figure 7 shows the installation of the bearings in the MEGS where it can be seen that they are mounted back to back, with the right hand bearing mounted in an axially compliant but radially stiff diaphragm (preload of 100 N). The diaphragm protects the bearing against thermally induced preload variations. In the launch configuration the off-load device separates the two bearings and prevents brinnelling. Operation of the off-load device also brings into contact the slipring which provides the signals for the pyrotechnics needed for the array and the MEGS off-load release.

II-4 Slipring Assembly

Because of the low torques requirement on the slip ring, a high diameter disc concept for the sliprings was abandonned in favour of a modular cylindrical assembly with a small external radius.



MEGS Slipring geometry

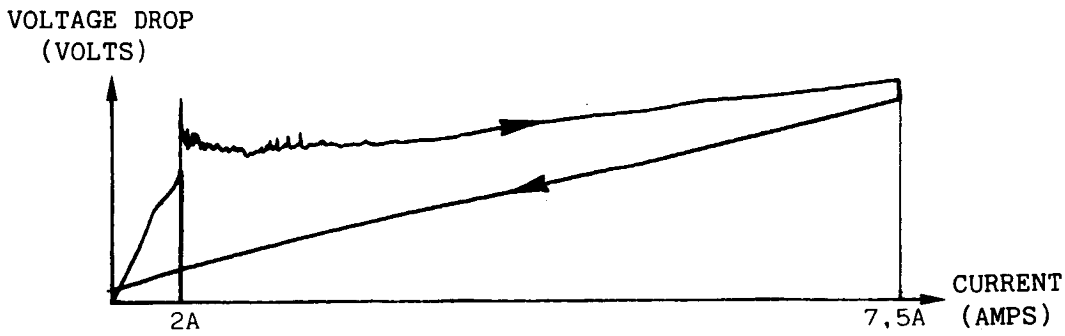
Figure 8

Figure 8 shows the principle of the slipring geometry. Note that the brush pressure is applied by means of a soft blade spring. This technique reduces the effect of temperature differentials and also allows for the 0.3mm displacement of the rotor when the off-load mechanism is applied. The slipring materials were chosen after a series of tests performed by CNES with material from Le Carbone Lorraine. The material chosen was Ag/Carbon/MoS2 (12% MoS2). As described above, the pyrotechnic sliprings were incorporated in the off-load device. In this way they did not contribute to the in-orbit frictional torques.

II-5 THE MEGS SLIPRING AGEING PROBLEM

One year after delivery of the MEGS, during integration testing on the SPOT 1 satellite at the MATRA facilities at Toulouse, anomalous values of contact resistance were found in both the pyrotechnic and the power/signal slipring assemblies. The problem was particularly severe for the pyrotechnic sliprings (which had to be tested before launch) where a typical value found was a 1000 ohm resistance compared with the expected performance of 1 ohm. Since the circuit was designed to cater for 40 mohms under a 7.5 amp nominal current, action was necessary to examine the phenomenon and find a remedy.

Although such a high contact resistance had not before been identified either at SEP or at MECANEX, Switzerland, where the sliprings were manufactured, some anomalies had been observed during tests to determine the "breakdown current" on the pyrotechnic slipring assembly.



Evidence of the "diode effect" during testing

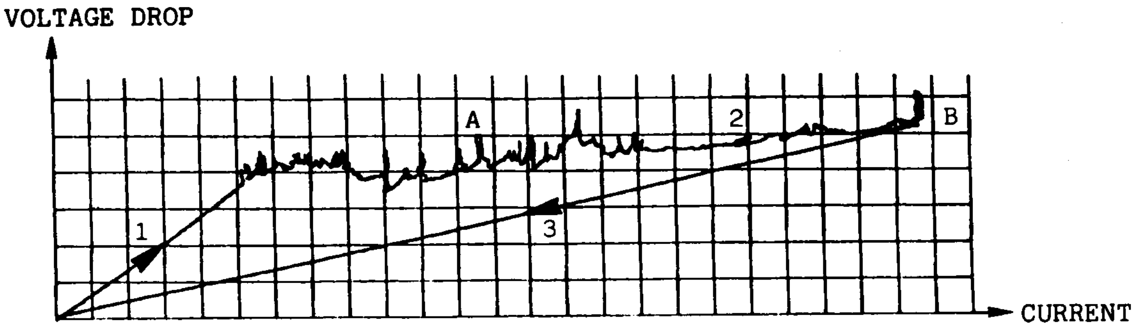
Figure 9

Figure 9 shows the results of such a test where it can be observed that the voltage drop that can be maintained across the slipring rises steeply until about 2 Amps has been applied and then "breaks away" rising only slightly for the remaining current rise to 7.5 Amps, the nominal current.

From these tests it appeared that there was some form of "diode" effect, the contact behaving normally after the nominal current was applied.

It was concluded that the high friction observed during integration was caused by a local pollutant which even if it were generated during ground use or storage would normally be rubbed off during operation by either mechanical or electrical action. The long storage prior to integration had enabled the pollutant to build up.

In order to check the electrical effect, a breakaway test was done on the "failed" unit where the current was increased up to the nominal current density of 30 A/cm2. The results had uniformly the same character for all slipring circuits, and showed the features given in Figure 10, with some variation in the current at which the different stages in the phenomenon were observed.



Breakaway tests on MEGS sliprings

Figure 10

Referring to Figure 10, Phase 1 ($I < 0.5$ Amps for the power lines) indicates a normal resistance/current relationship. The peaks, such as that indicated by A in the figure, correspond to the burning off of the pollutant layer. Phase 2 is diode type behaviour and indicates a "semi conductor" presence, possibly a layer of Ag2O or Ag2S. At the point B, where the nominal current density is achieved, all the pollutant layer has been burnt off, and in Phase 3 the slipring shows a nominal performance, indicating that the contact area has been cleaned.

Although these tests showed that current alone could clean the surface and in actual fact gives a predominant effect, both current and movement are necessary to eliminate the Pollutant layer. The results also showed that the attainment of a critical "breakaway point" was necessary to achieve the cleaning function.

Following these investigations, the SPOT 1 MEGS sliprings were cleaned just prior to launch in 1986 and subsequently operated well within their specifications in orbit. Investigations are now being performed to investigate the origin of the pollutant layer and to identify materials that could be used to avoid the problem.

IV THE MOGS (Mecanisme d'Orientation de Générateur Solaire)

IV-1 The Major Requirements

Following the successful development of the MEGS it was decided by CNES to fund at SEP the design of a solar drive specifically for GEO applications.

The main requirements were :

- Low mass Mechanism	< 5 Kg		Electronic < 2.5 Kg
- Load capabilities	800 N	//	along rotation axis
	1500 N	⊥	perpendicular to axis
	200 Nm	⊥	perpendicular to axis
- Power capability	6 kW		at 50 V
- Accuracy	+/- 0.2 deg		at EOL
- Life	10 years		

III-2 Technical description of the MOGS

Figure 11 shows a scheme drawing of the MOGS. In this design, to reduce the overall dimensions and mass, the slipring assemble is placed between the bearings which are SNFA SEA 55 angular contact bearings, lubricated by the ESTL lead lubrication process. The use of a diaphragm mounted bearing reduces the sensitivity of the mechanism to temperature variations whilst maintaining the high radial stiffness required by the application.

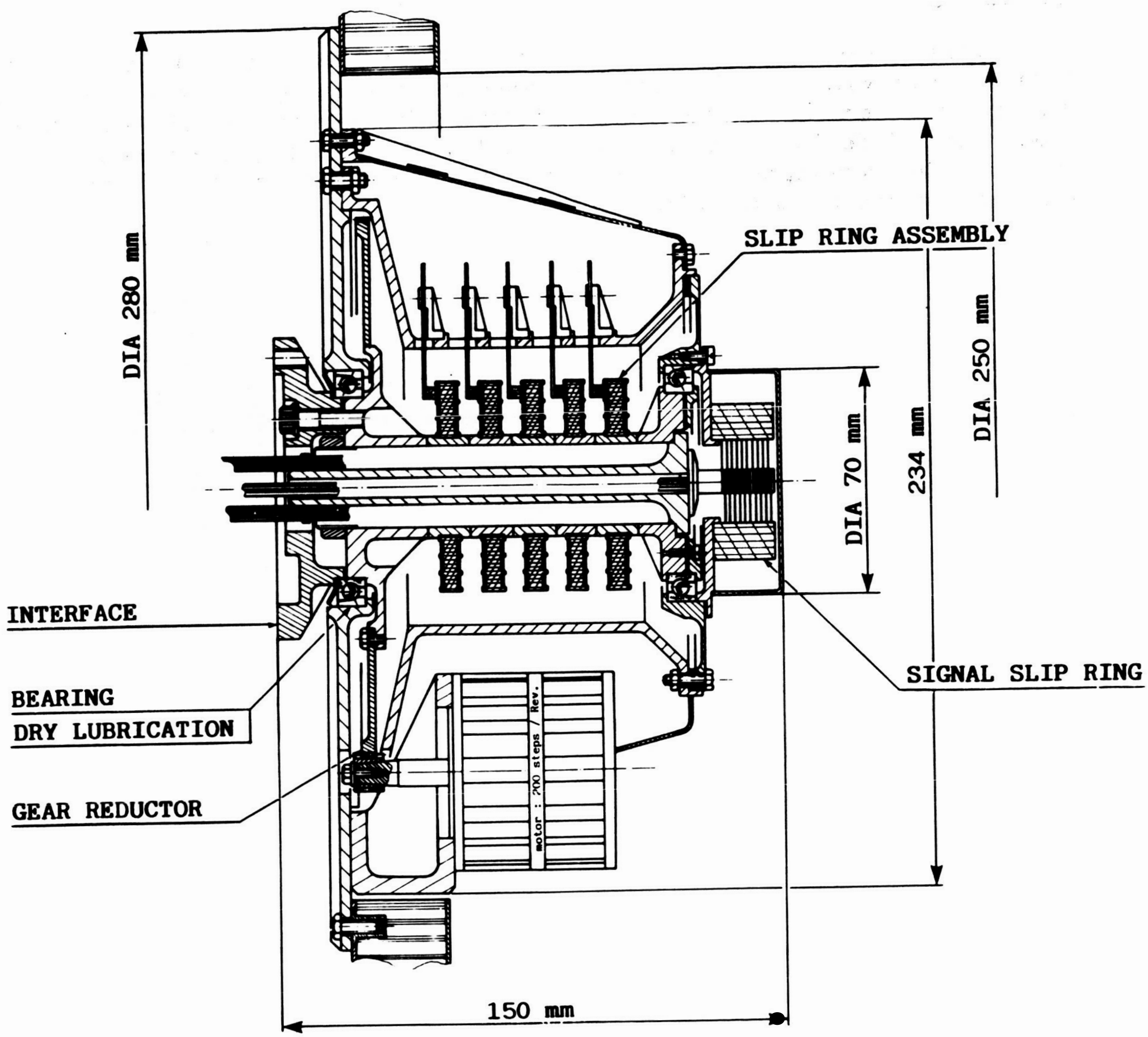
The power sliprings utilise 4 cylindrical modules, each with 6 rings capable of carrying up to 8 Amps. The same slipring and brush materials as for the MEGS are used for the power circuits but for the 20 signal circuits NEY ORO brushes sliding against gold rings are used.

Although the MOGS design has benefited from the experience gained from the MEGS and GIOTTO Despin Mechanism programmes, the lesser importance of speed stability has meant a change in approach to drive control, and an off-shaft stepper motor is used, driven by a shaped pulse, to improve the dynamic characteristics.

The high pointing accuracy is achieved by use of a 200 step/rev MOORE REED stepper motor driving a 15:1 gear giving a shaft step of 0.12 deg (worse case backlash, including wear effect, is 0.08 deg). A magnetic encoder (+/- 0.1 deg accuracy), is fitted to the MOGS, allowing datum checking and the possibility for in-orbit reconfiguration on the satellite.

The gear system utilises a steel pinion rotating against a NUFLON-N treated steel gear. This combination was selected following load-representative vacuum testing at CNES and CETIM. Thus the whole MOGS is dry lubricated.

The effect of temperature differentials on the MOGS performance is minimised by the use of the diaphragm loaded bearing, the linking of the motor to the MOGS drive shaft by a flexible connection, and by the use of a special "constant gap device" which maintains the gear-pinion play at a constant value.



MOGS

(Mécanisme d'Orientation de Générateur solaire)

Figure 11

IV CONCLUSION

This paper has described the salient features of two solar array drives whose development has been undertaken by SEP and CNES. The designs illustrate the radically different approaches which originated from the differing design requirements. A slipring problem occurred late in the development of the MEGS and the paper indicates how recovery action can be taken with this type of failure.